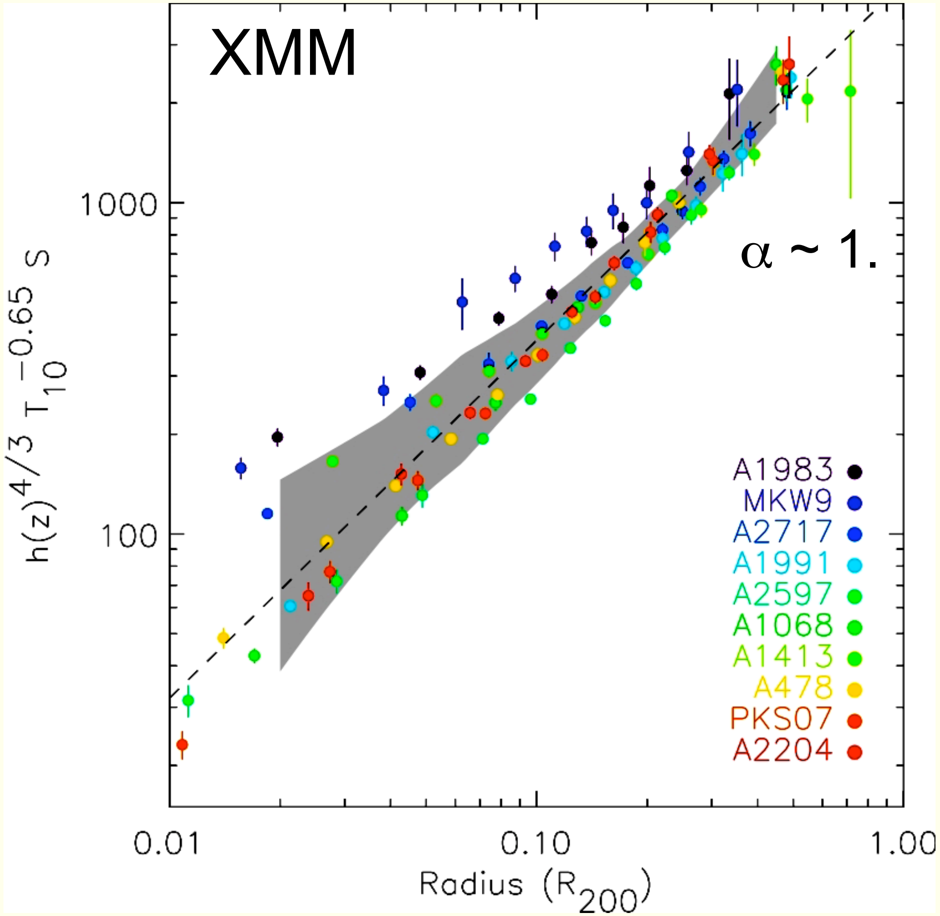
Profiles scaled $S \propto T^{0.65}$



Pratt, Arnaud & Pointecouteau, 06
also Piffaretti et al, 05

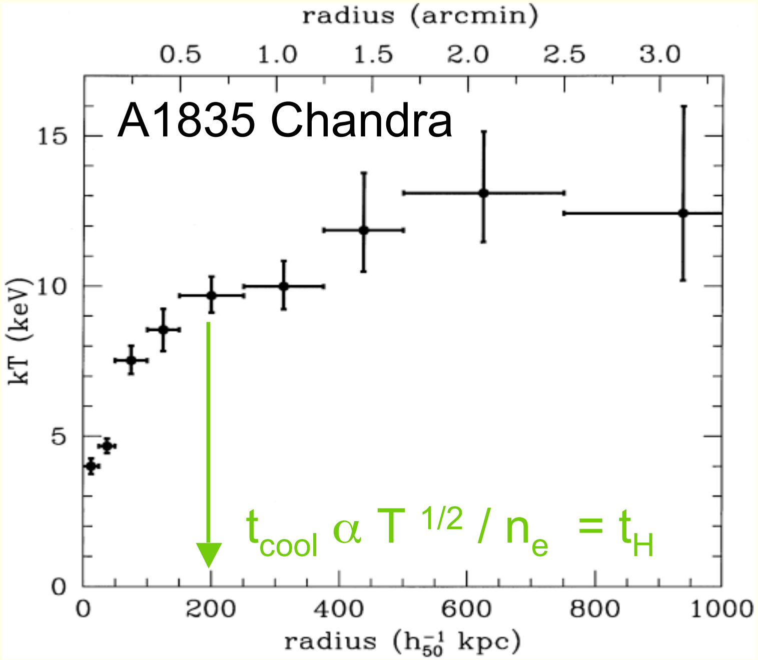
- Self-similar down to 2 keV
  beyond core with ~ standard slope

- No flat entropy core
  ⇒ simple pre heating models rejected

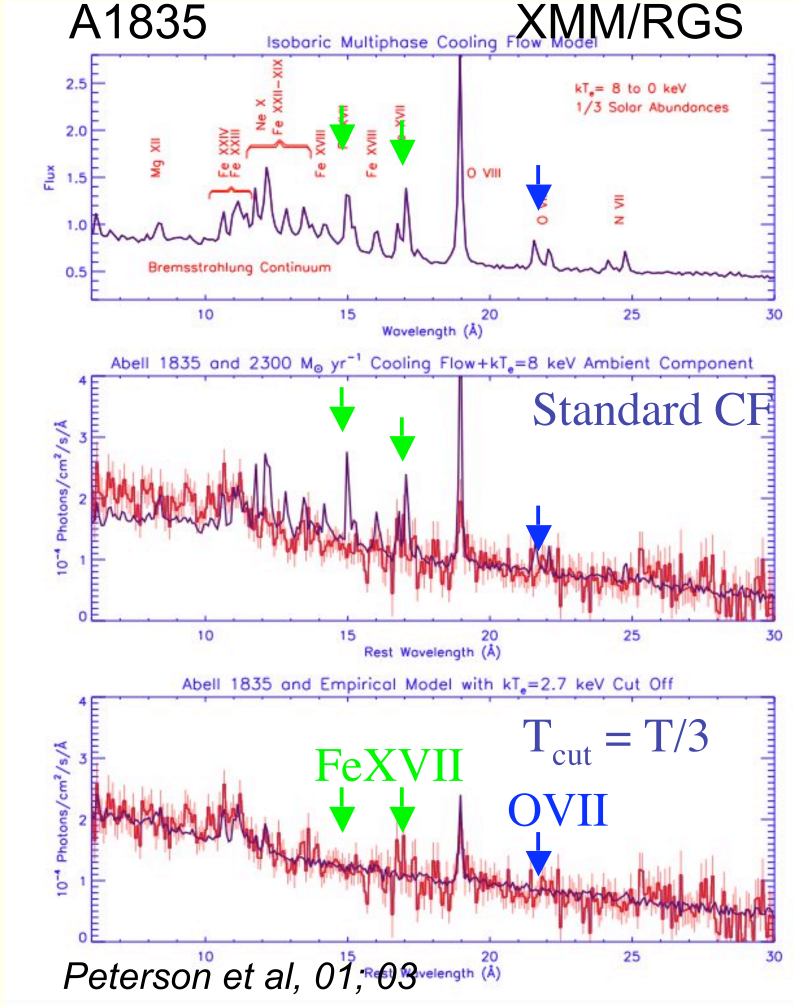
- Larger dispersion in center
  ⇒ effect of cooling/AGN/merger

Gas history depends on both cooling and SN/AGN heating

The center: a laboratory of non gravitational physics (I)



Schmidt et al, 01

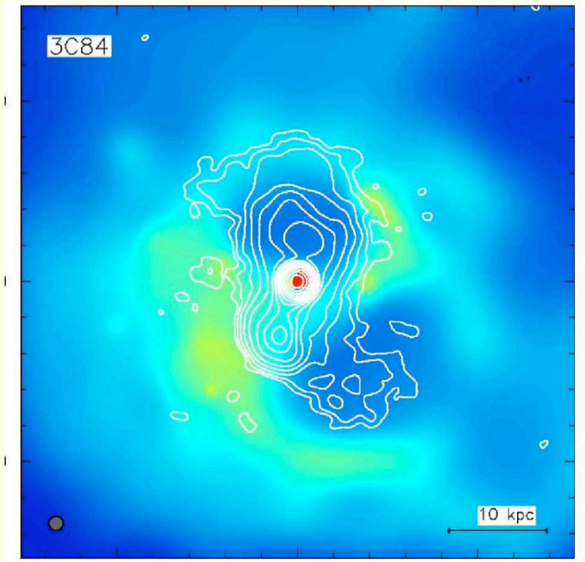


Peterson et al, 01; 03

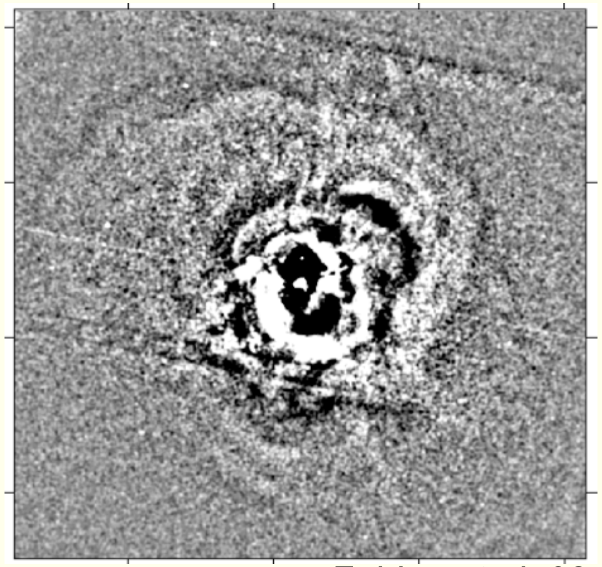
Cooling in the center

But not as expected

The center: a laboratory of non gravitational physics (II)



Fabian et al, 00



Fabian et al, 03

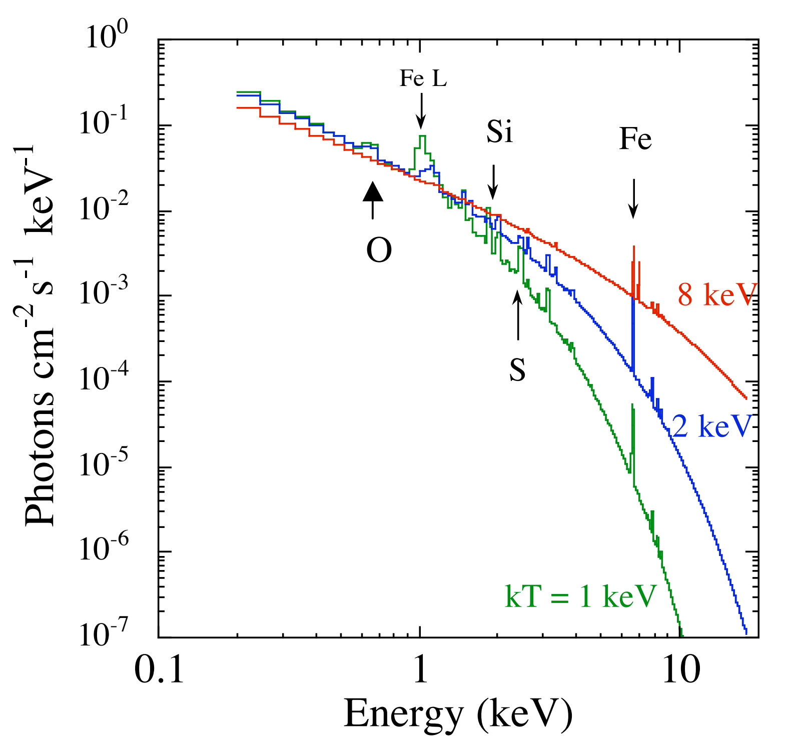
- X-ray cavities evacuated by radio source weak shocks and sound waves
- cool rims (no strong shocks) *[see Blanton 03 review, but see McNamara, 05]*

Complex dynamical interaction with AGN activity

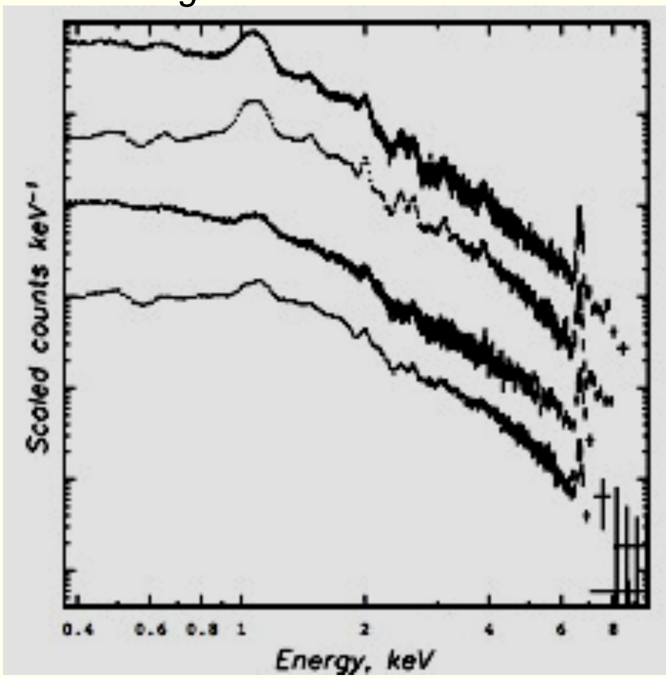
Core properties not well understood !
Balance between cooling and AGN heating? effect of conduction ?

Galaxy feedback: the ICM enrichment (I)

dN(E)/dE ~ n_e^2 V [g(E,T) $T^{-1/2}$ exp(-E/kT) + lines]



Finoguenov et al 01



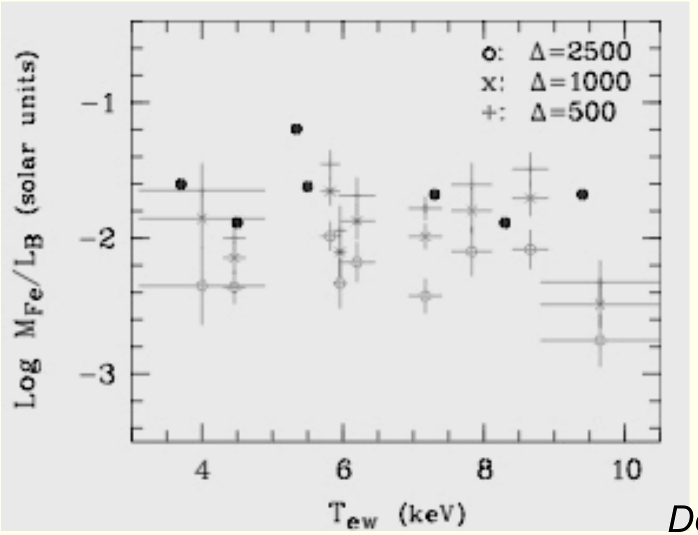
Center
~1 keV

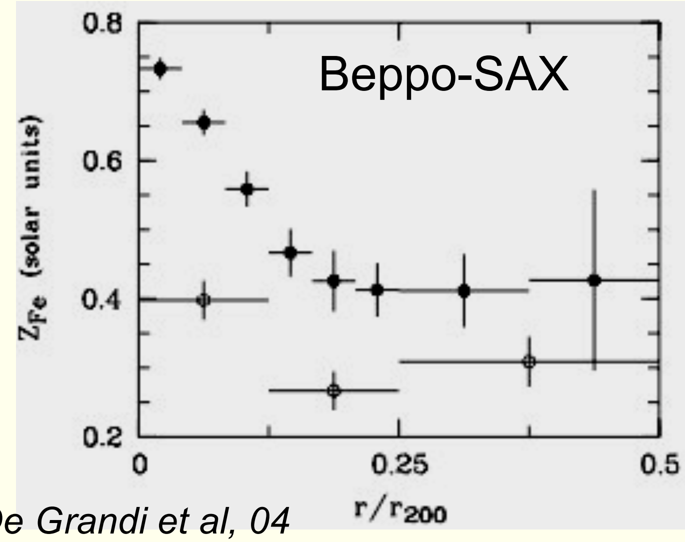
Outside
~2.7 keV

M87/Virgo

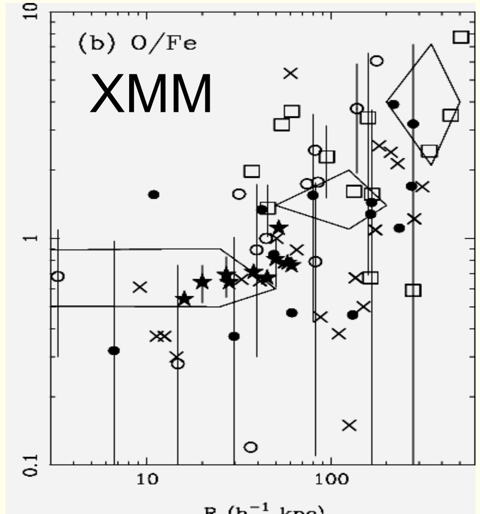
ICM enriched in heavy elements
Abundances other than [Fe] difficult to measure for high kT
(massive cluster, outside cool core)

Galaxy feedback: the ICM enrichment (II)





De Grandi et al, 04



Tamura et al, 04

- Constant M_{Fe}/L ratio (see also *Arnaud et al 92*)

  No abnormal low (< *) abundance in groups center *Buote et al, 02, 03*

  => global yield and constraints on IMF

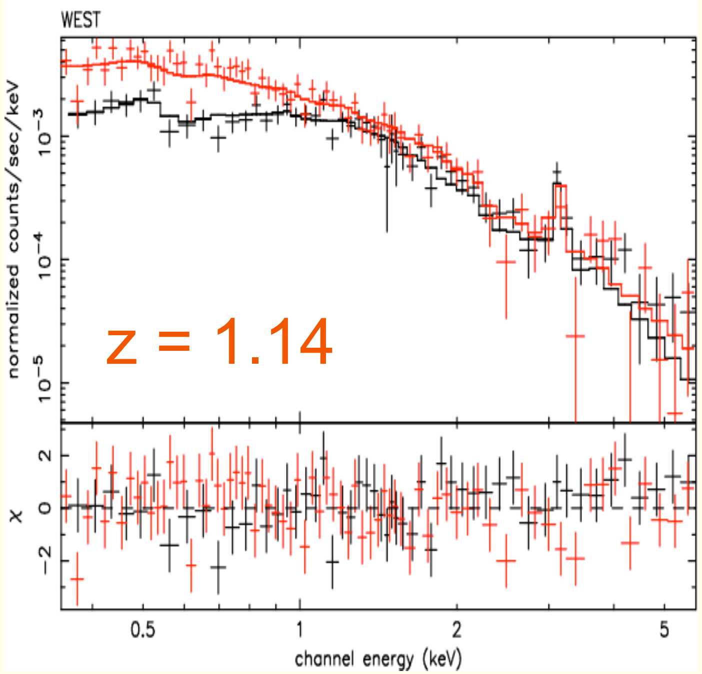
- Central Fe abundance peak
- O/Fe increase with radius; Si/Fe and S/Fe flat

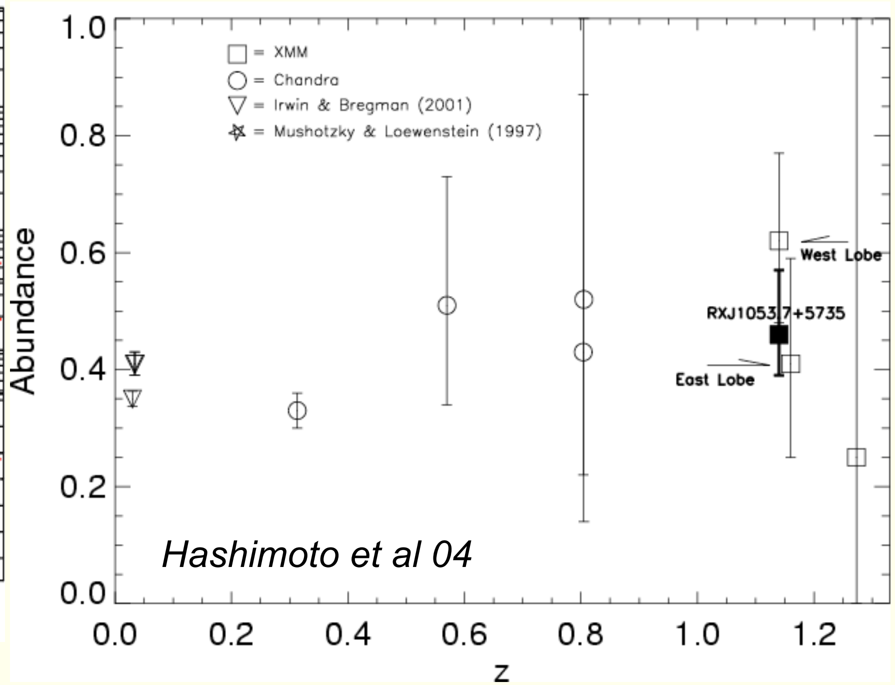
  ⇒In center: production by cD (and long lived cool core *Bohringer et al, 04)*

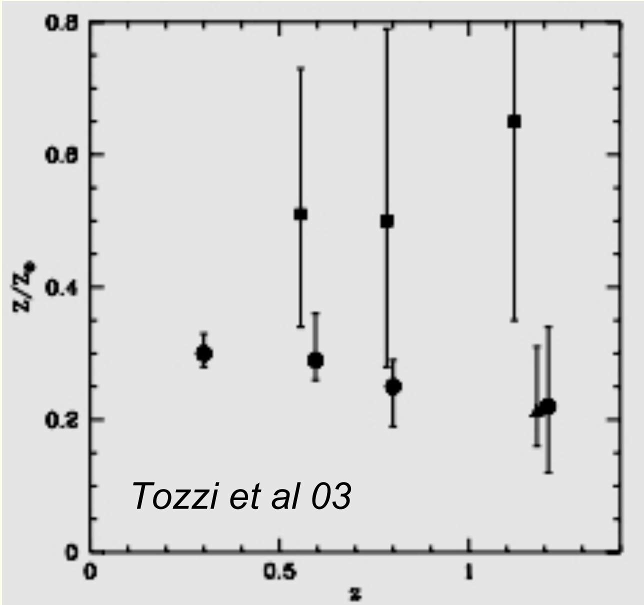
  by SNI and SNII and massive star formation

  ⇒ In outer part: higher contribution from SNII

  AND even constraints on SNI/II yields (*Finoguenov et al, 02)*





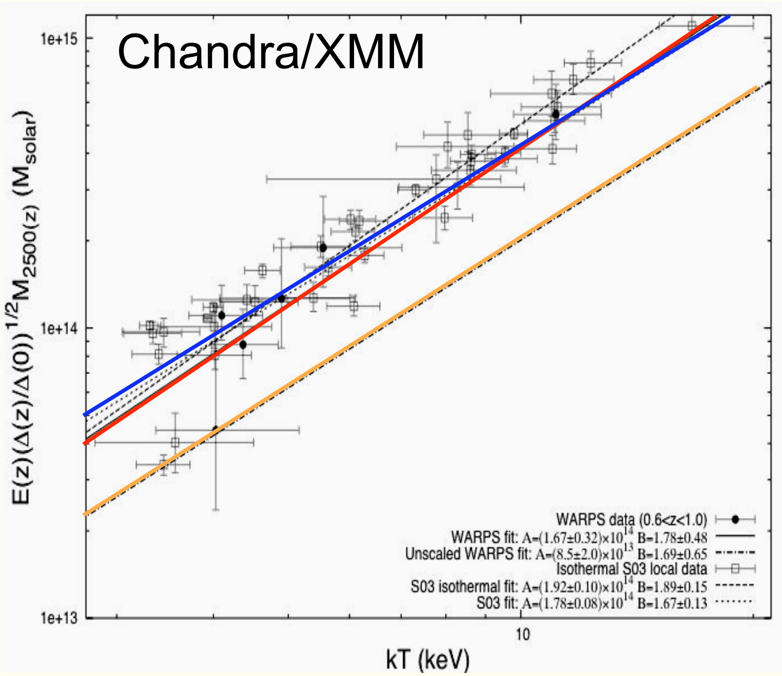


No evolution of [Fe] abundance up to z>1.1

Consistent with early enrichment

What about evolution of the scaling laws ?

Evolution of the scaling laws



Maughan et al, 05

Remember (simple) expectations

- Collapse at a fixed density contrast:

$$GM/R^3 = \langle\rho\rangle = 200\ \rho_c\,(z)$$

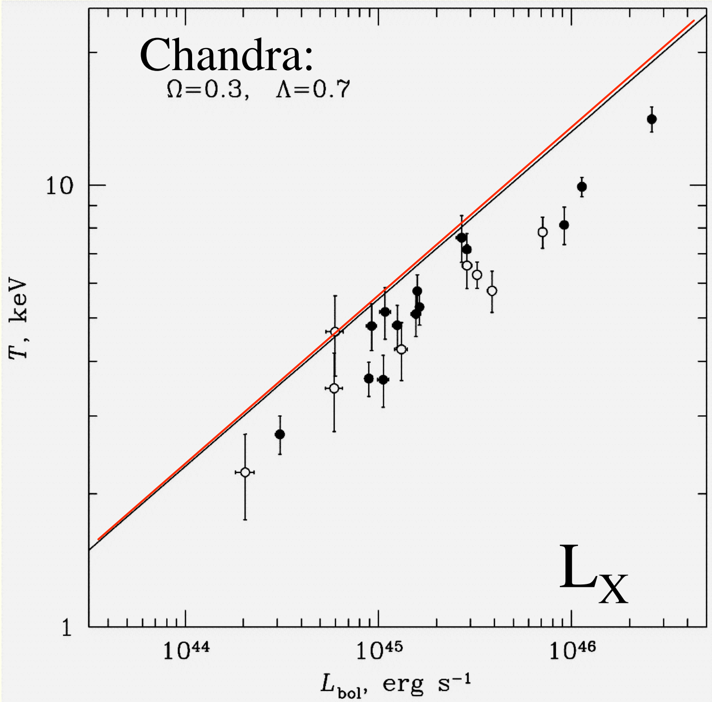
- Evolution of the scaling laws

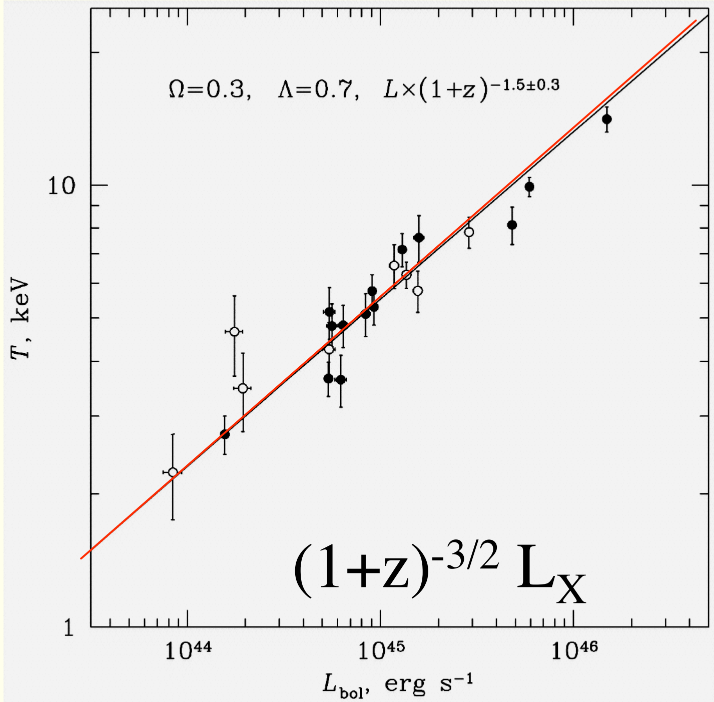
via $\rho_c\,(z) \propto h^2(z)$

e.g. $M \propto h^{-1}(z)\ T^{3/2}$ $\quad L_X \propto h(z)\ T^2$

The overall picture provided by this study of the evolution of the cluster scaling relations is that within the statistical limits of the current data, the evolution of galaxy clusters out to $z \approx 1$ is described well by the self-similar model. “

The L_X-T relation does evolve





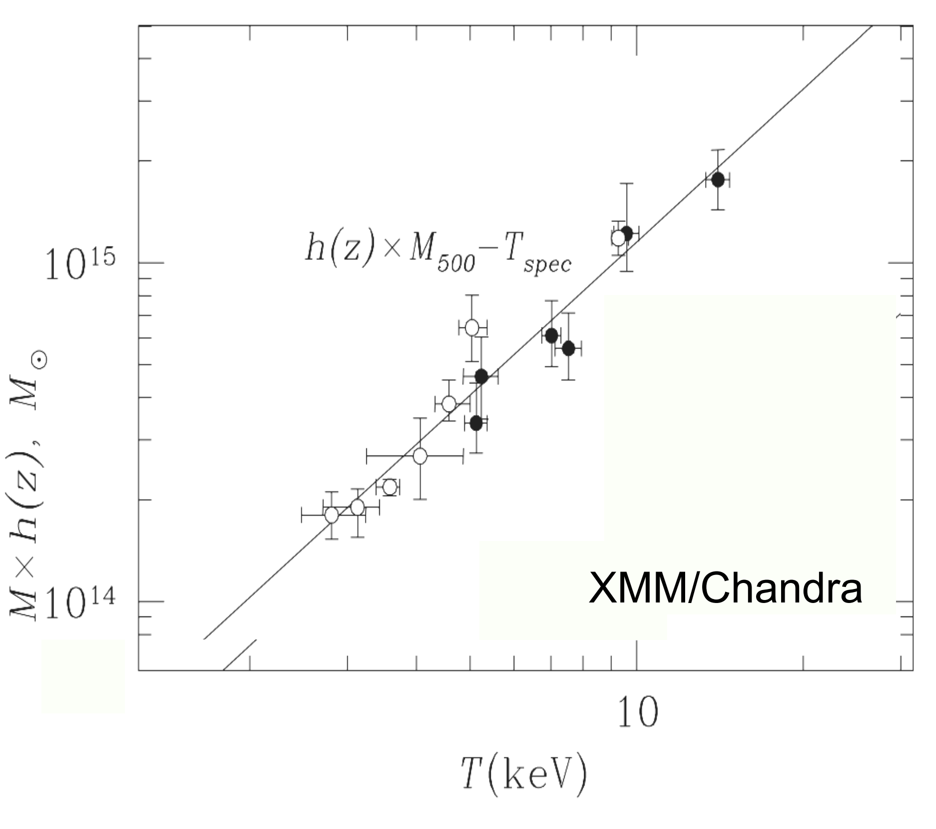
Vikhlinin et al, 02

The amount of evolution is still uncertain: expected $L_X \alpha\ h(z) \sim (1+z)^{0.6\text{-}0.9}$ 30% (z=0.5)

- [Lumb et al]: $(1+z)^{1.52\pm0.26}$; [Vikhlinin et al] $(1+z)^{1.5\pm0.3}$; [Maughan et al] $(1+z)^{1.4\pm0.2}$ > expected
- [Ettori et al]: $(1+z)^{0.62\pm0.28}$ = expected and $h(z)^{-1} L_x\ \alpha\ (1+z)^{-1.04\pm0.32}$ < expected

!!! Systematics !!!: def integration region; ref. local relation (calibration, CF…); theor.evolution

First comparison of apples with apples



Kotov & Vikhlinin, 05, 06

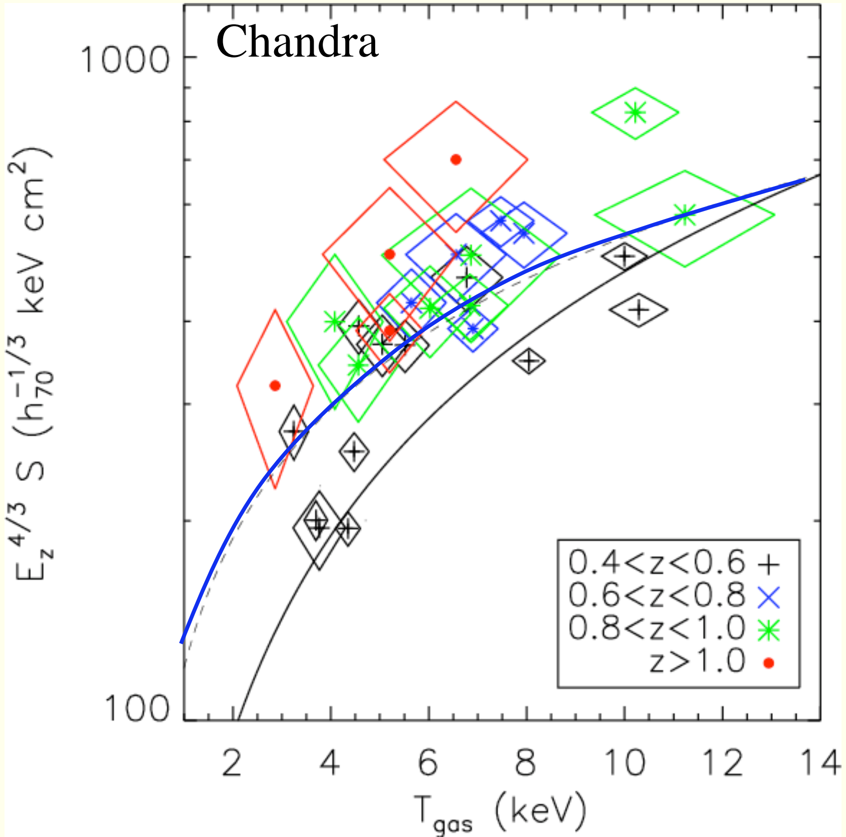
- Local M-T from Chandra ~ XMM
- High z (0.4 -0.7) mass from:
  XMM/Chandra
  spatially resolved kT profiles

Evolution as expected

$M_{500} = h(z)^{1.02\pm0.20}\ T^{3/2}$

“

And the entropy evolution (thermodynamical *history*)?



Ettori et al, 04

may be lower than expected:

$h(z)^{4/3}$ S -T = $(1+z)^{-0.14\pm0.04}$

but large scatter

Future progresses expected on formation physics

from

structures and scaling laws

using

larger unbiased samples

archives, LP and serendipitous surveys

$\Rightarrow$ Intrinsic scatter

$\Rightarrow$ Evolution

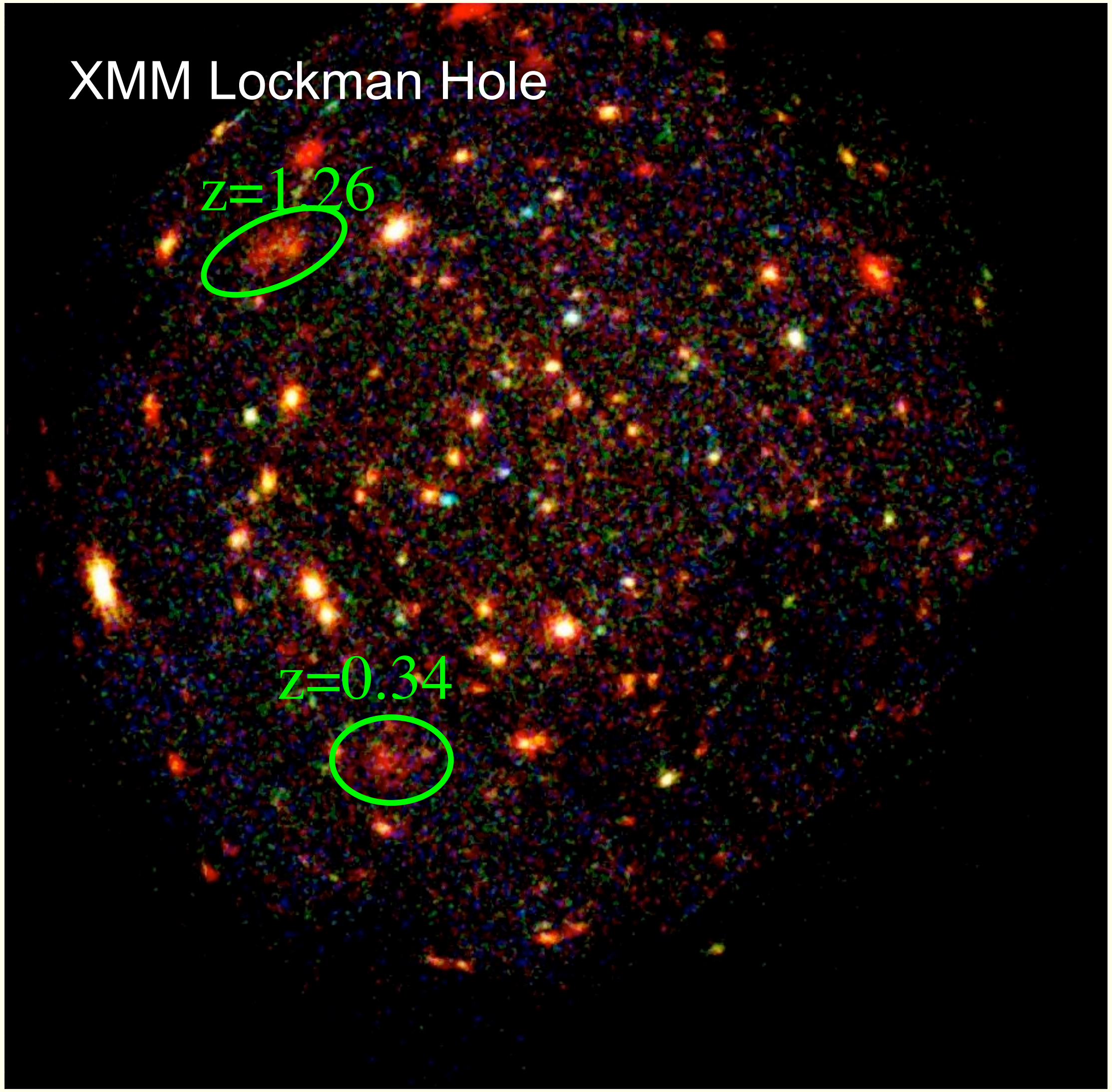
Conclusions II

With XMM and Chandra

- Universal mass profiles with shape as expected
  => modelling of the *Cold* DM collapse OK
- Gas do obey self-similarity up to high z and low mas
- But it differs from purely gravitational model
  => importance of cooling AND galaxy feedback
  => still to be better understood

X-ray cluster surveys

Detecting clusters in X-ray



Hasinger et al, 01

The X-ray sky:

- AGN (point sources)
- Clusters (extended)
  [beyond the galactic plane]

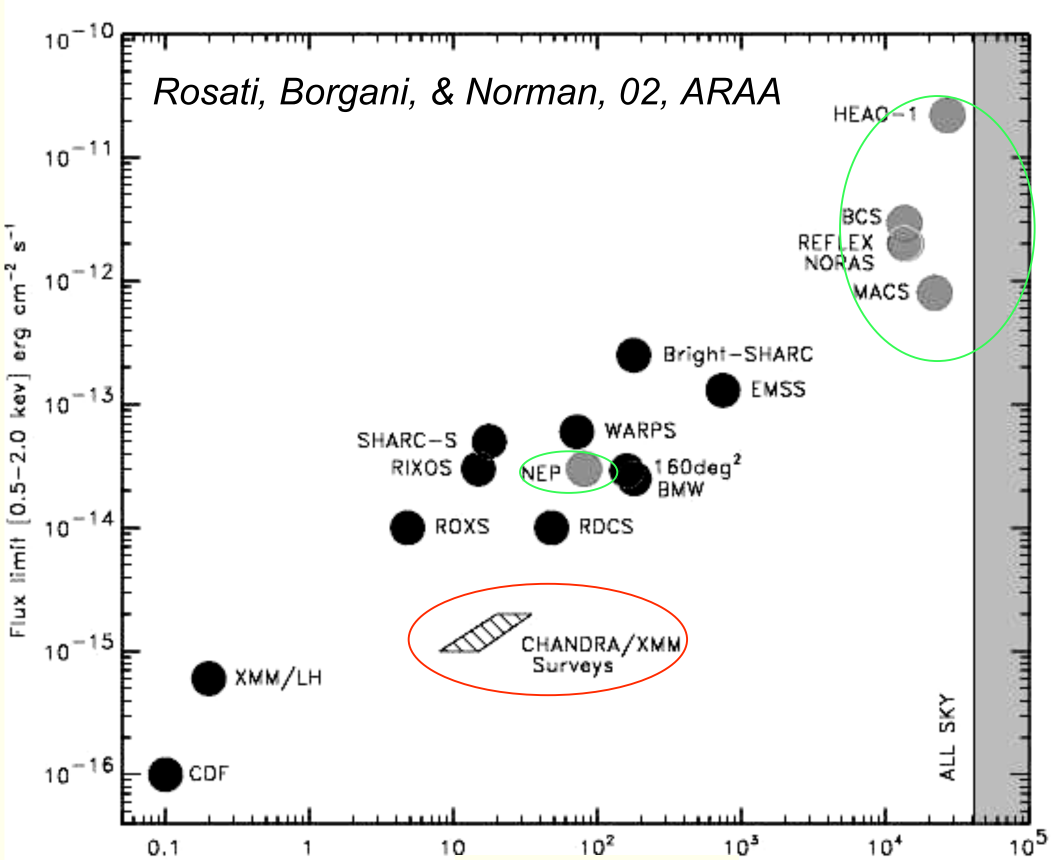
Advantages of X-ray surveys

- X-ray => true DM potential well
- high contrast, no (few) confusion
- well controlled selection function
  => Space densities

Some difficulties

- optical follow-up (z)
- understanding selection function

Existing and planned X-ray cluster samples



Area (deg^2)

From all sky surveys

- HEAO
- ROSAT (RASS)

=> mostly local samples
e.g: Reflex: 447 clusters

From serendipitous surveys

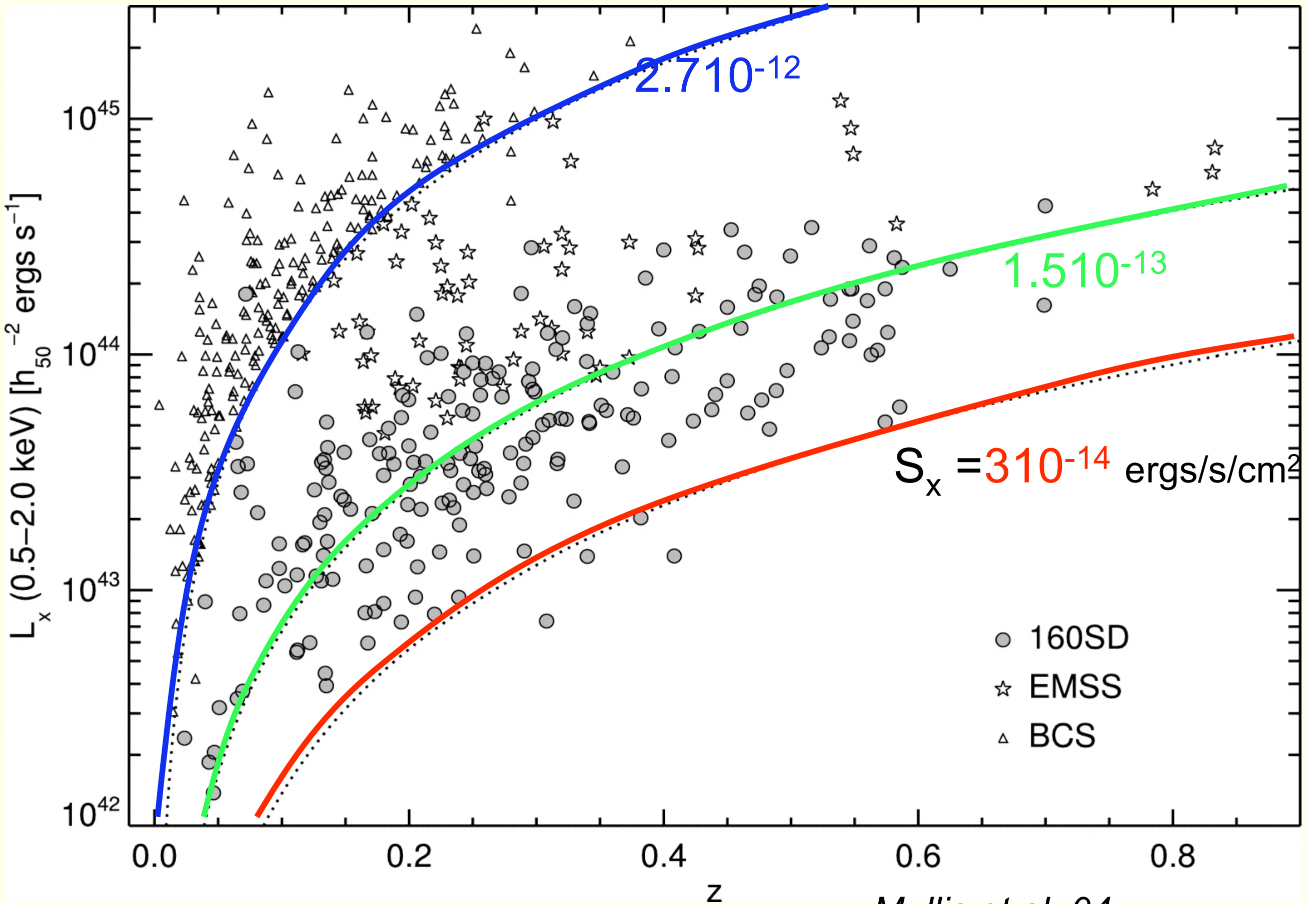
- Einstein: EMSS
- ROSAT:

⇒ high z (>0.3) samples
From 12 to 80 (120) clusters

•XMM (chandra)

Information : L_x in original catalog, some shape parameter..
(all) kT (and possibly mass) from follow-up by *next generation* satellite

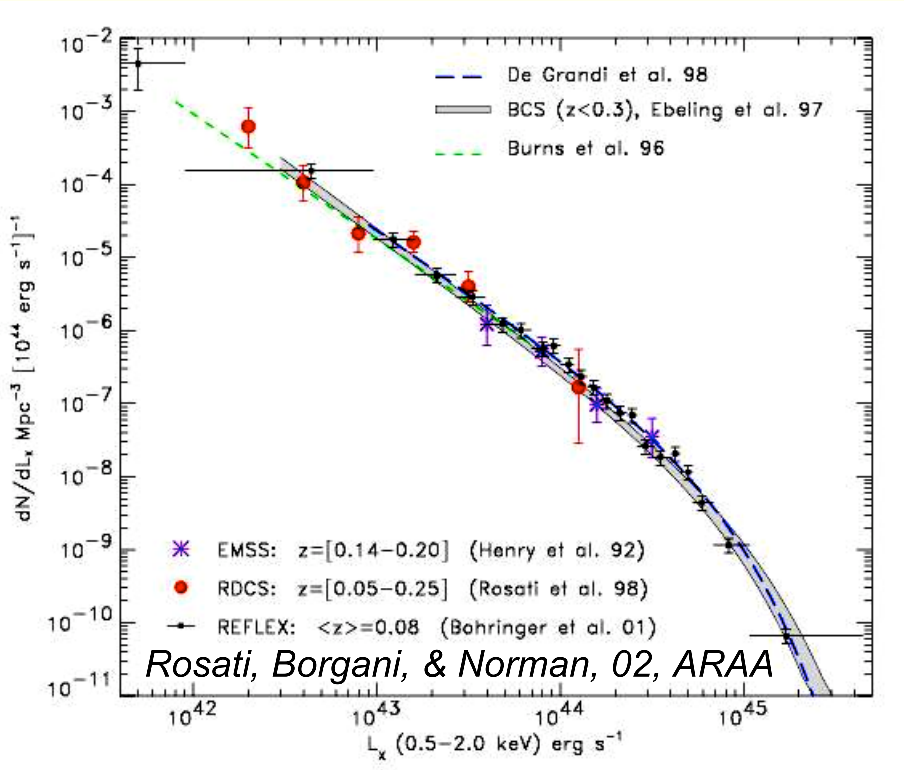
Cluster distribution in the L_X-z plane

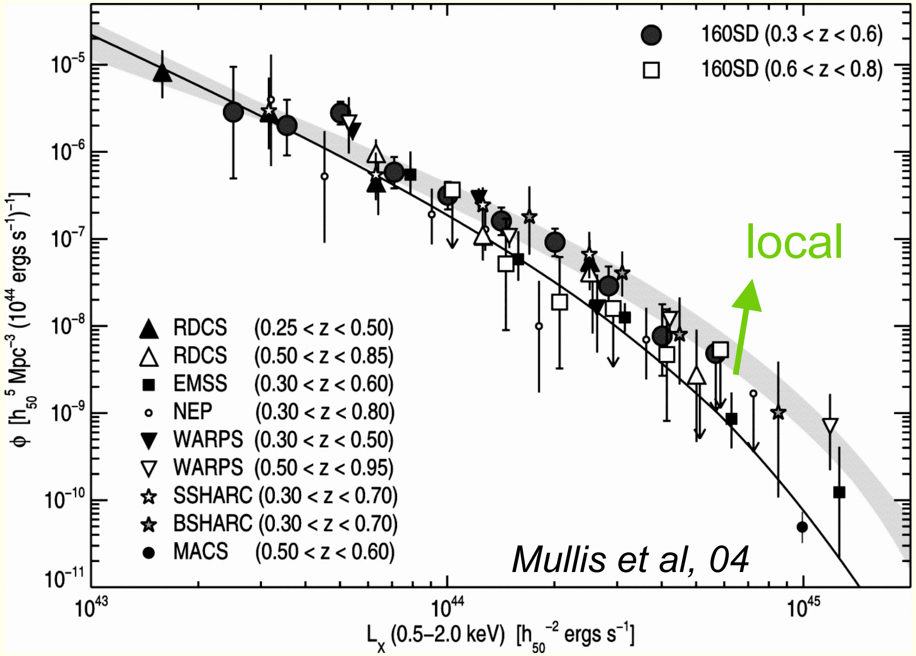


Mullis et al, 04

Flux limited surveys => Lower mass increases with z

The luminosity function





Luminous (massive) clusters are rarer

The bright end of the XLF evolves

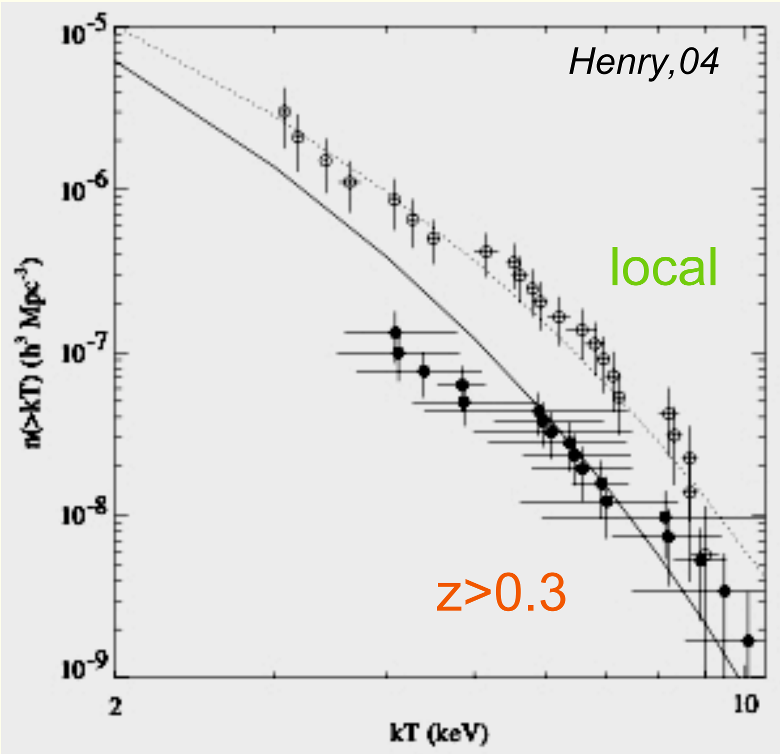
significant $z \gtrsim 0.5$ $L_X \gtrsim 5 10^{44}$ erg/s

⇒ Survey area important

⇒ if S_{lim} ➘ but Area ➘ => extend (low) mass coverage, not z coverage!

Examples of other functions

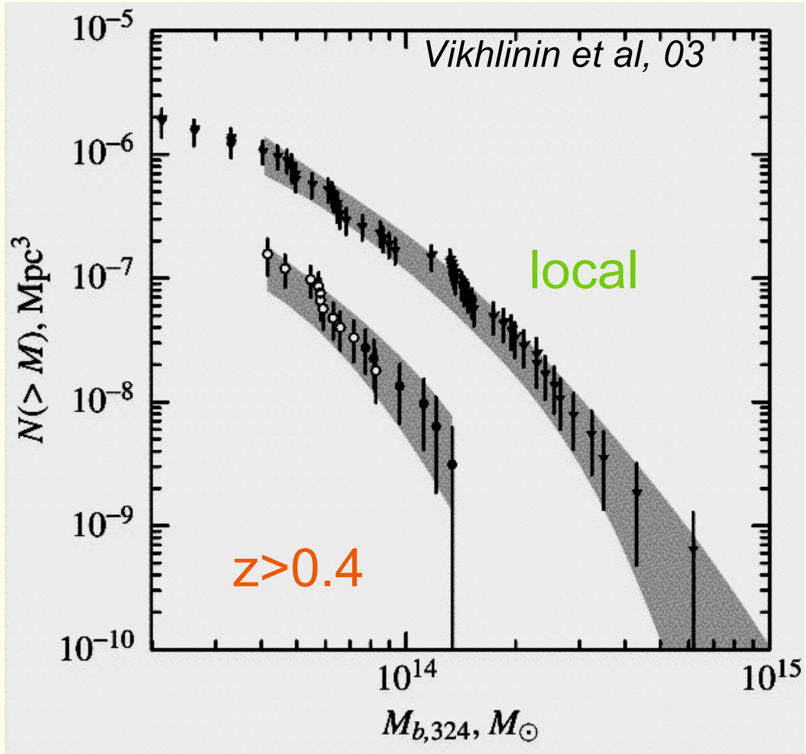
The XTF



High z: ASCA follow-up of EMSS

still need: L_X-T

The $XM_{gas}F$

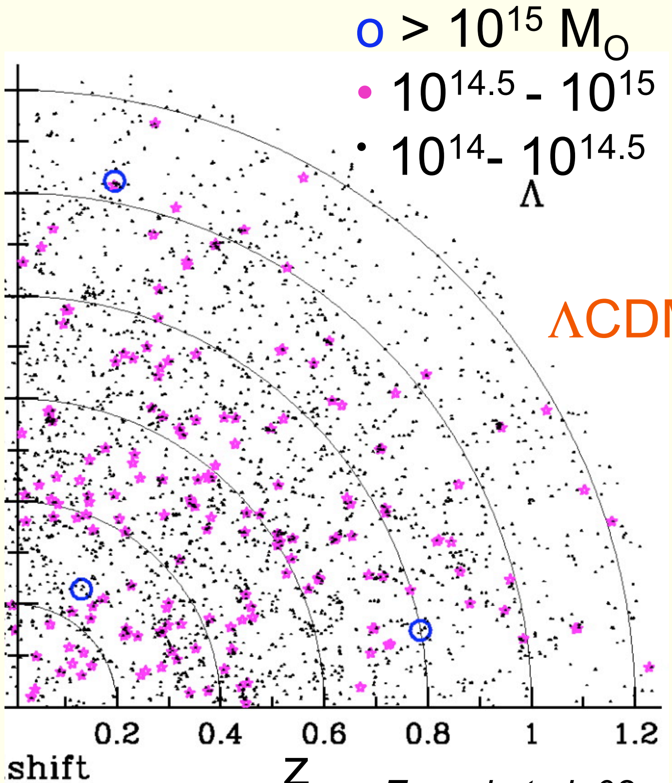


CHANDRA follow-up of 160SD

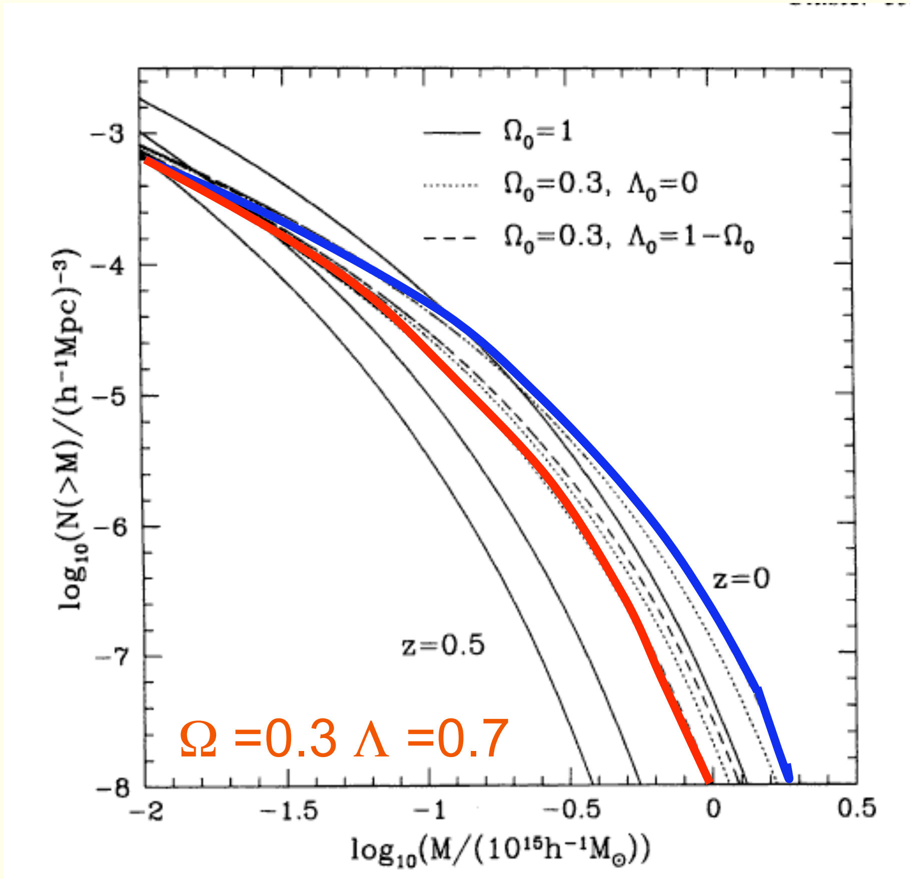
L_X-M_{gas}

to estimate selection function/survey volume

The CDM cosmological scenario predictions



Evrard et al, 02



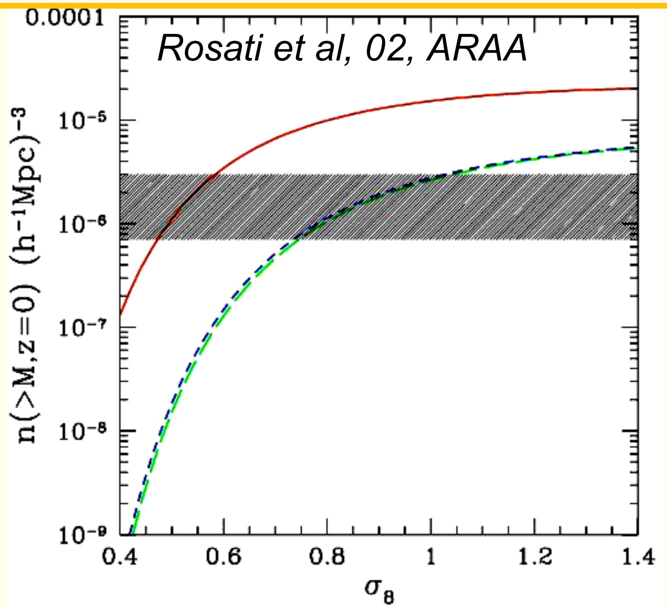
Eke et al, 96

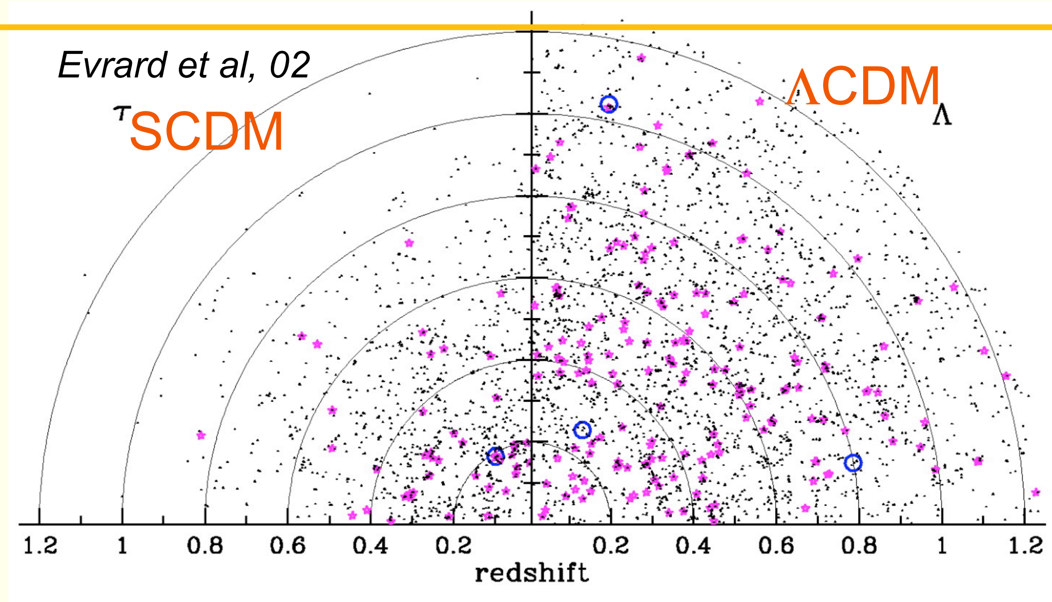
The XL(T,Mgas..)F at various z reflect the mass function and its evolution

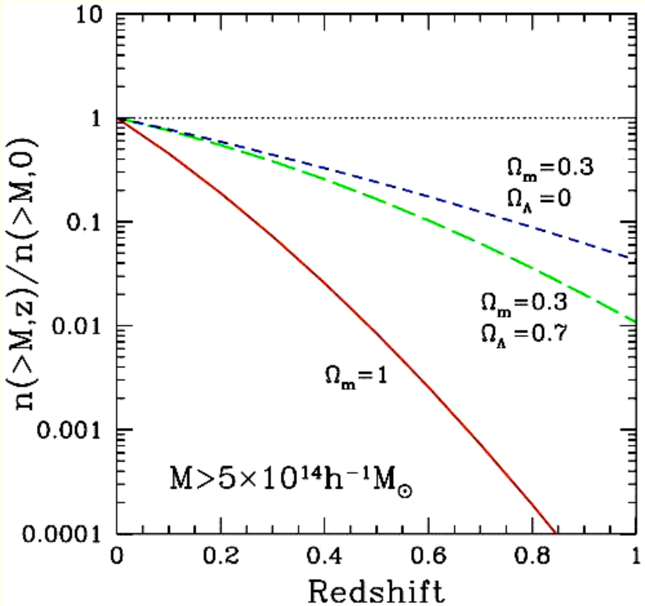
=> Clusters as cosmological probes ?

Cosmological parameters with X-ray observations of clusters

From cluster abundance







Principle

⇒ N(M,z) depends on Ω_m, σ_8 [Ω_b n, h, Ω_Λ]
(fluctuation spectrum + cosmo)

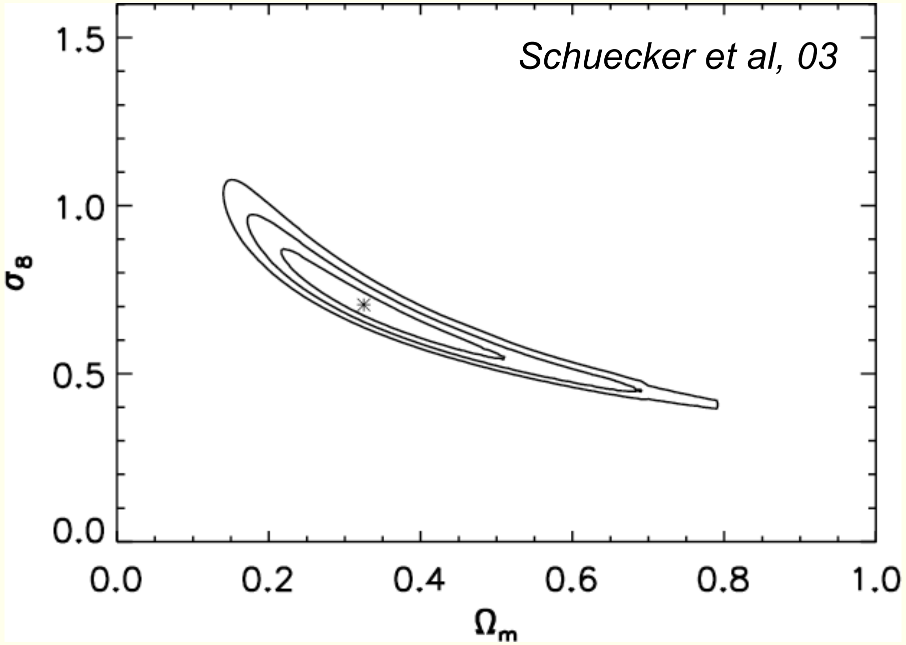
⇒ Evolution strongly depends on Ω_m

Caveats

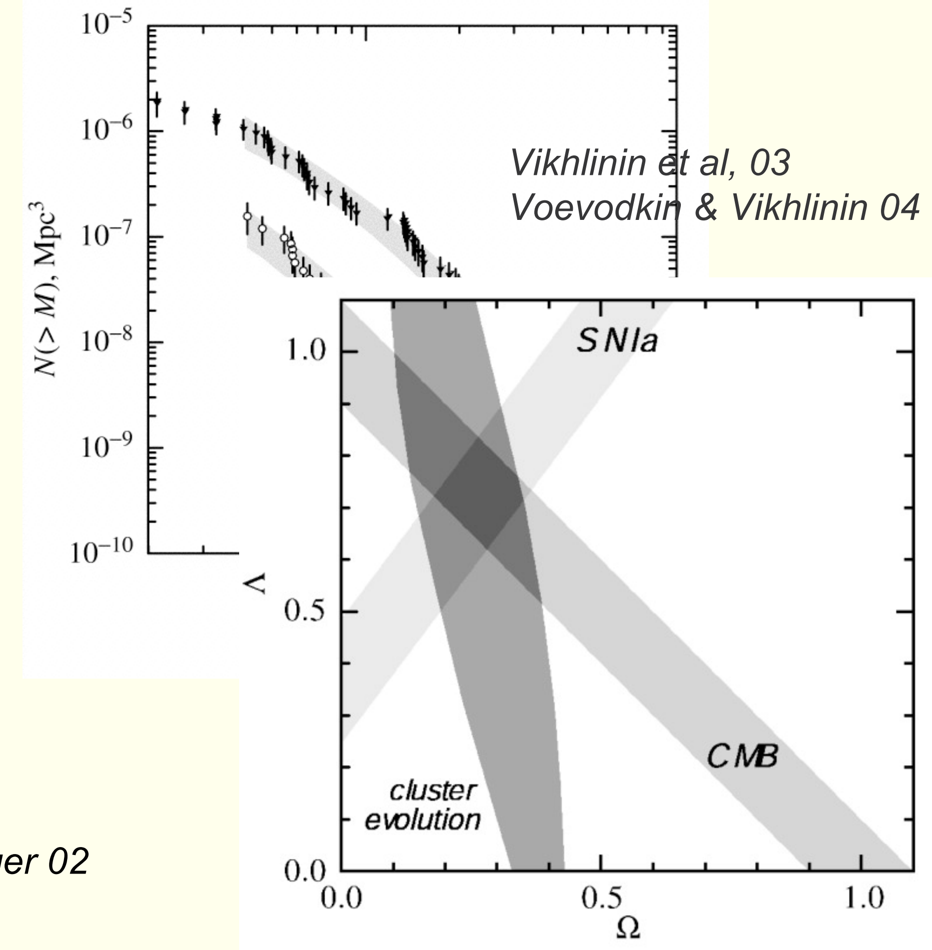
use proxies for the mass: L_x T …

⇒ need to know scaling laws
incl scatter & normalisation

(Illustrative) Results:



Reflex *local* XLF and M-L from *Reiprich & Böhringer 02*

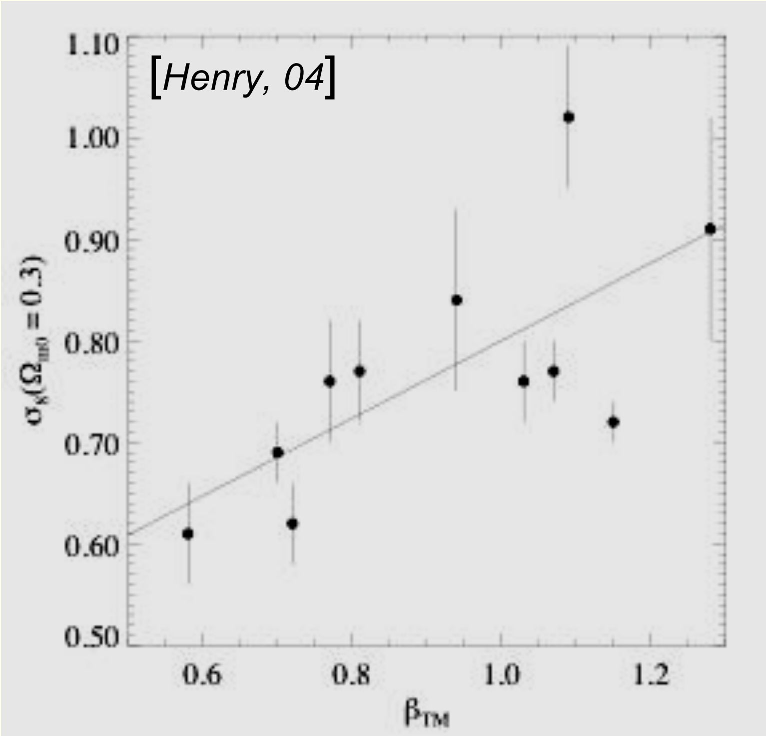


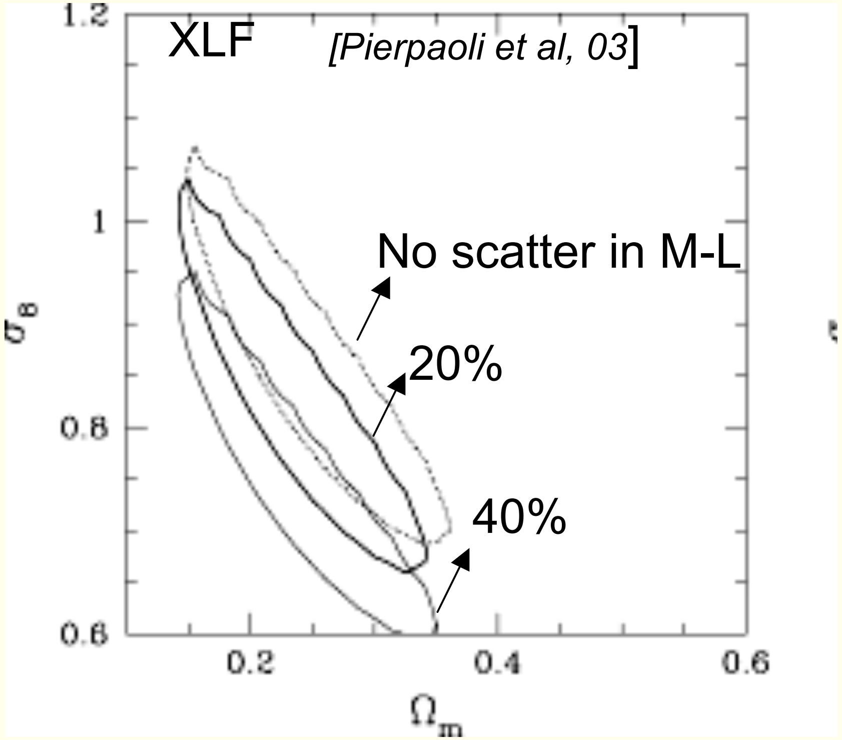
Evolution break $\sigma_8\Omega_m$ degeneracy

For $\Omega + \Lambda = 1$
Ω= 0.24 ±0.12 (68%)
σ_8 = 0.72 ± 0.04

- General consistency on Ω_m between various XF studies (but see next slide)
- Complementarity with SN and CMB
- Excellent agreement of σ_8 with new WMAP3yr data

On the importance of the knowledge of the scaling laws





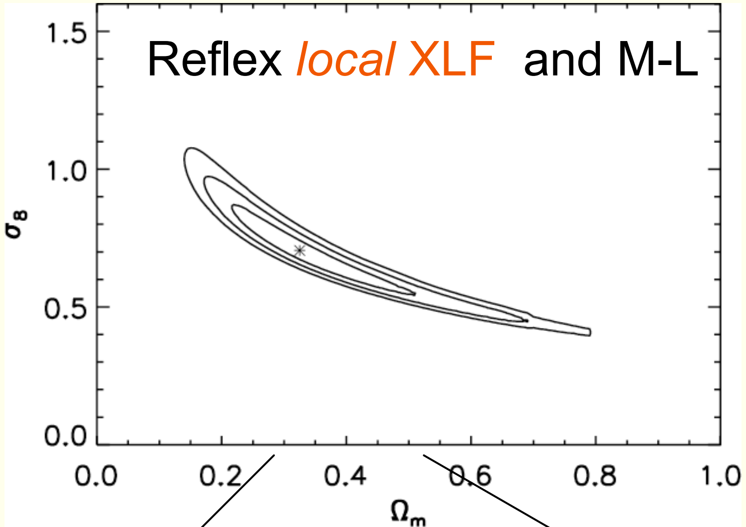
Discrepancies between various published results mostly due to M-T normalization used

Main source of systematic uncertainty

Knowing and taking into account properly the scatter in the M-L (or M-T or etc..) relations is essential.

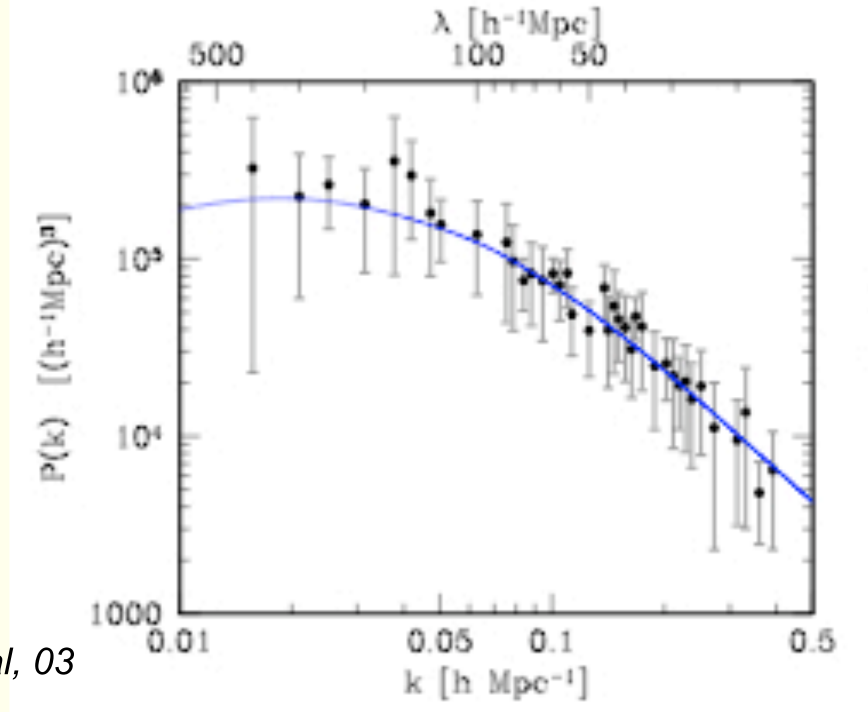
Using local cluster clustering

Breaking the degeneracy ..



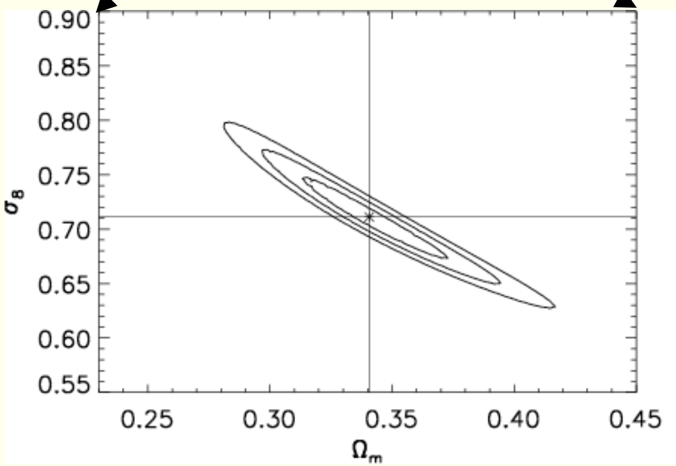
Schuecker et al, 03

+



Power spectrum from Reflex survey

=

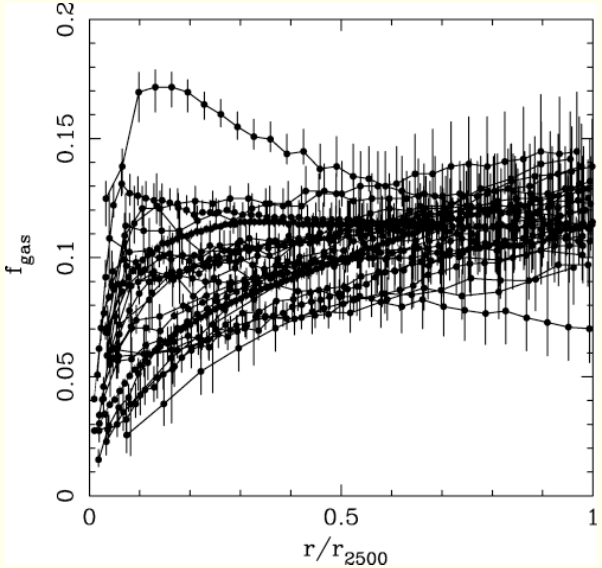


For $\Omega + \Lambda = 1$

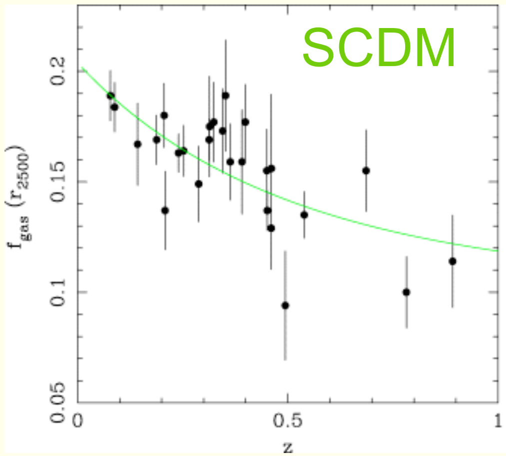
Ω= 0.34 ±0.04 (68%)

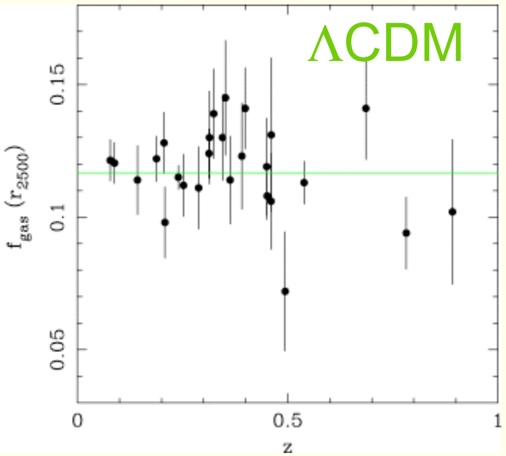
σ_8 = 0.71 ± 0.04

From gas mass fraction



Allen et al, 02, 04





Principle: $f_{gas}\,(1 + f_{gal}/f_{gas}) = \Omega_b/\,\Omega_m$

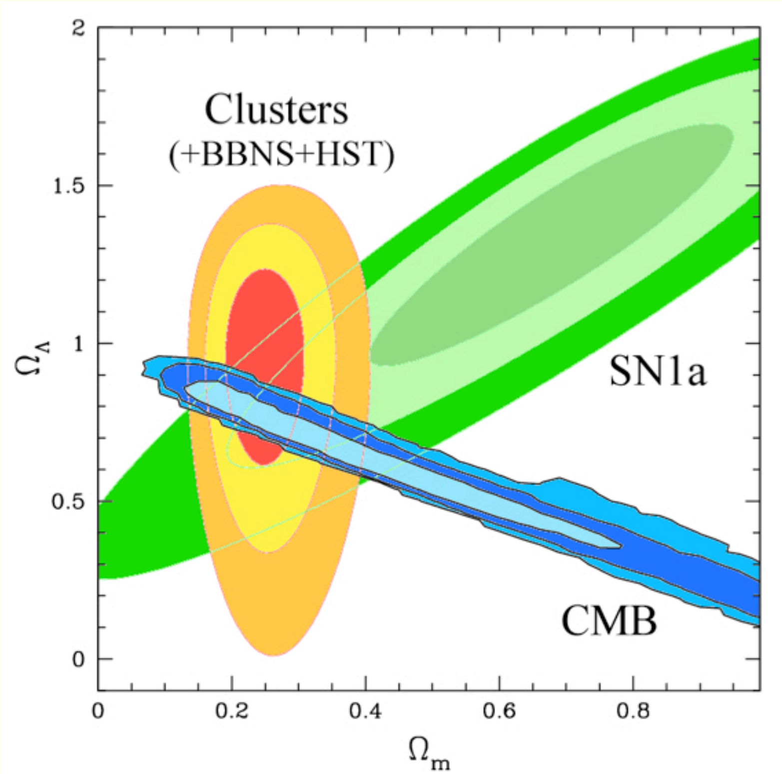
$$f_{gas}^{SCDM}(z) = \frac{b\,\Omega_b}{(1+0.19\sqrt{h})\Omega_m}\left[\frac{d_A^{SCDM}(z)}{d_A^{mod}(z)}\right]^{1.5}$$

Normalisation => Ω_m

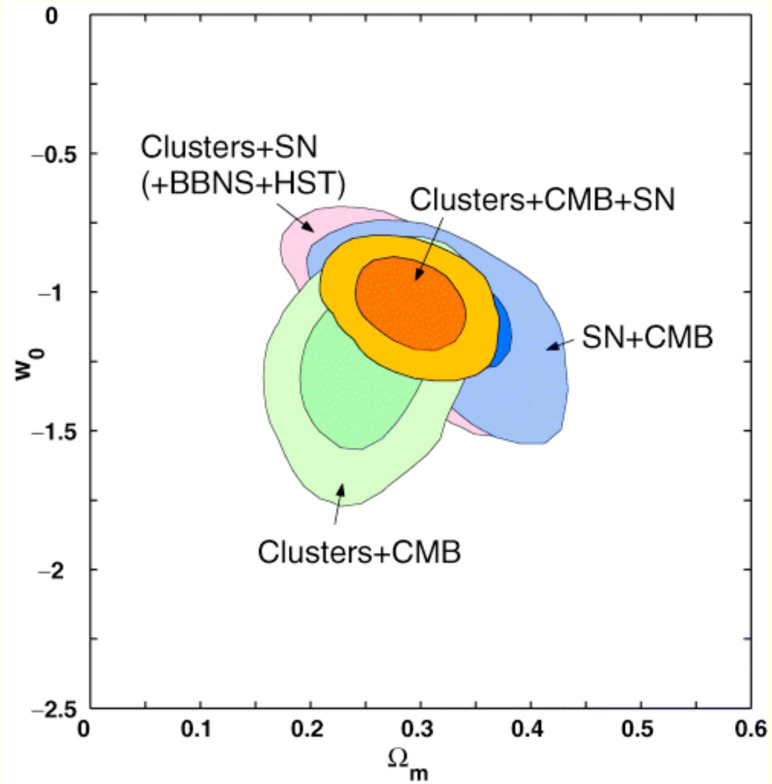
Distance indicator (as SNI) => $\Omega_m\ \Omega_\Lambda$ w

Caveats

- f_{gas} increases with mass
  => high mass clusters
- Bias factor depending on radius
  => extrapolation (~20% effect)
  => compare at same δ and M
- Assume f_{gas} do not evolve



Allen et al, 04



Rapetti, Allen & Weller, 05

Priors: $\Omega_b h^2 = 0.0214 \pm 0.02$; $h = 0.72 \pm 0.08$

$\Omega_m = 0.245 \pm 0.04$
$\Omega_\Lambda = 0.96 \pm 0.2$ (68%)
> 0 at 3σ

Complementary to CMB and SNI

Constraint on dark energy very promising

Conclusions III

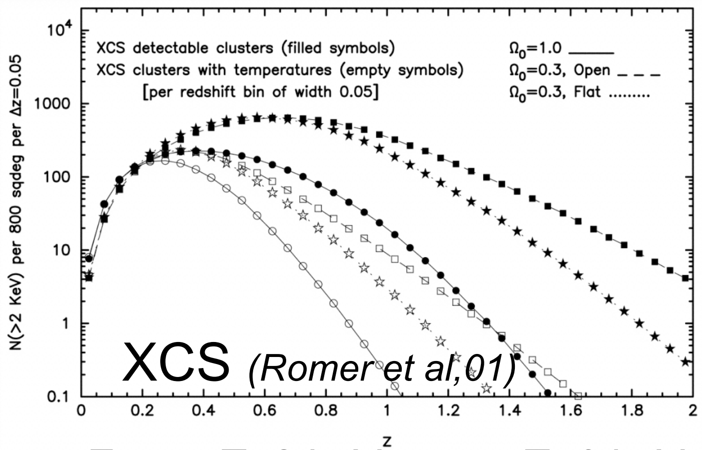
- Several independent cosmological tests from X-ray clusters

  ⇒ Fair sample of the Universe : Ω_m
  ⇒ Standard candles: H(z) : $\Omega_{m,}$ $\Omega_{DE,}$ w
  ⇒ Abundances N(M,z): growth rate of structures : $\Omega_{m,}$ $\Omega_{DE,}$ w, σ_8
  ⇒ Cluster clustering: idem

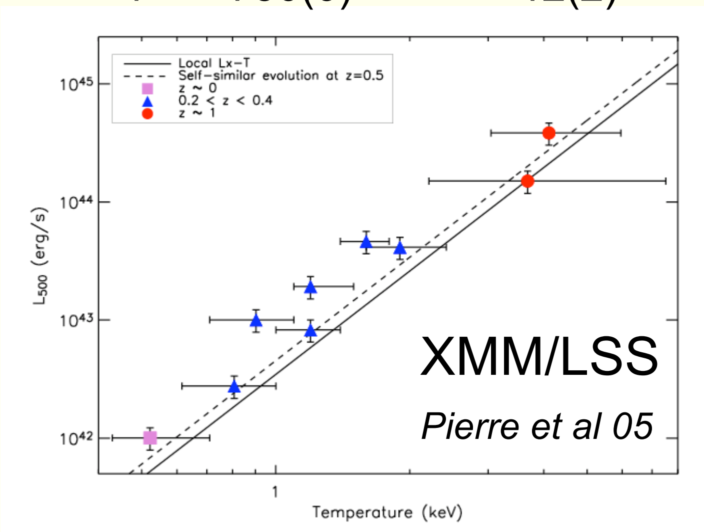
- Powerful tests
  ⇒ Complementary with CMB , SNI, weak lensing etc..
  ⇒ Excellent agreement of σ_8 (0.72 ± 0.04)
  with new WMAP data (0.74±0.06)
  ⇒ Low Ω_m confirmed, now measured to ±20%
  ⇒ Start to give constraints on Dark energy

Some prospects

XMM and Chandra continue ……



Z	T>2 keV	T>6 keV
>0	8300(1800)	61(42)
>0.3	7600(1200)	54(36)
>1	750(6)	12(2)



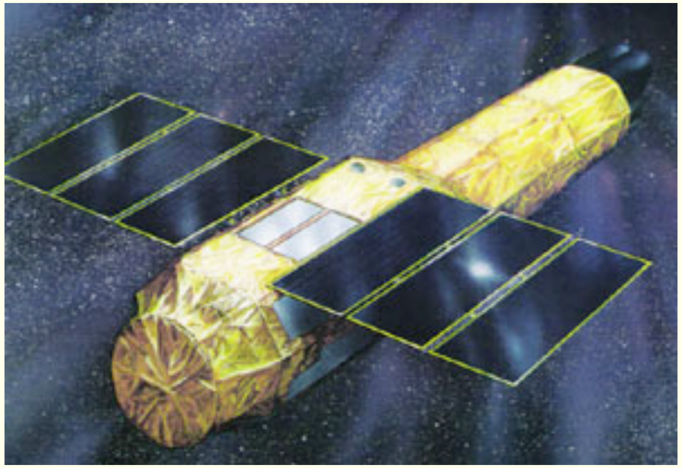
Future progresses expected:

- Formation physics from
  structures and scaling laws
  from larger unbiased samples
  archives, LP and serendipitous surveys

  ⇒ Intrinsic scatter
  ⇒ Evolution of scaling laws
  ⇒ Morphology evolution

- Cosmology:
  => follow-up of ROSAT surveys
  => new XMM surveys (XCS, LSS …

New missions



SUZAKU, launched in 2005

Japan mission (with collaboration from US)

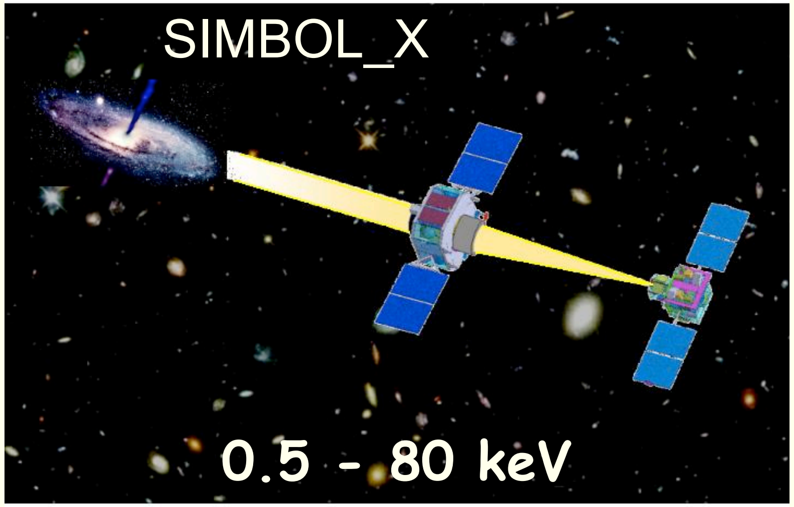
- Low background, e.g cluster outskirt studies
- Better spectral resolution at low E, e.g Ab studies
- Hard X-ray detector => non thermal emission

also NeXT project

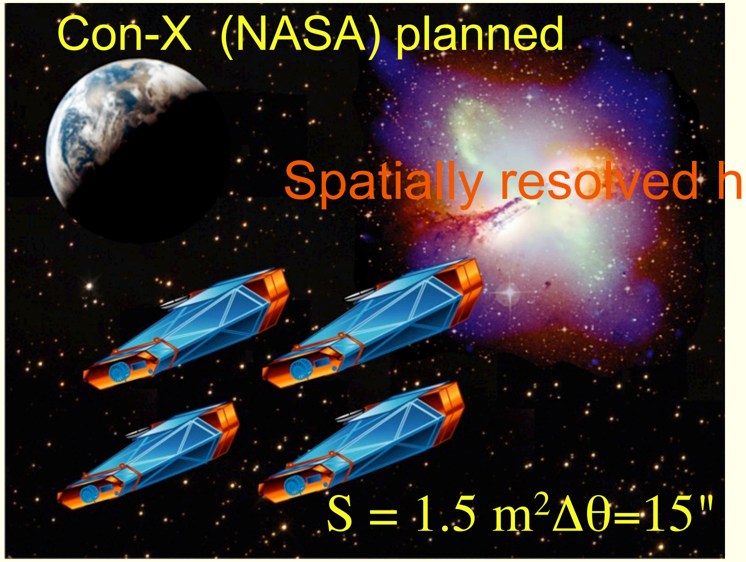
Specialized missions under study for <2012 launch

- SIMBOL-X => first spatially resolved spectroscopy up to 60 keV
  => non thermal emission

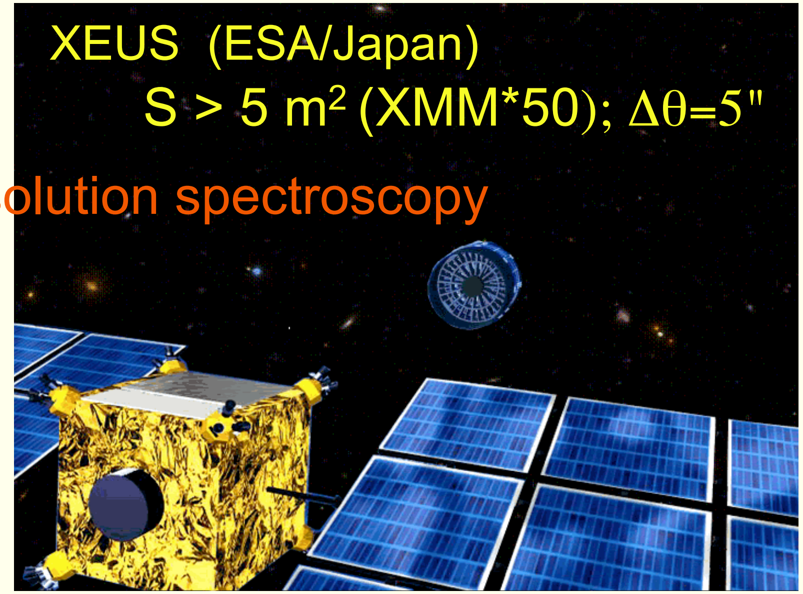
- eRosita => cluster survey for DE study.



Next generation observatories (> 2015)



Spatially resolved high resolution spectroscopy



The full history of the hot Universe ….

- early BHs
- from first structures -> today massive clusters
- nucleosynthesis

compl. to 'cool' Universe study (ALMA, JWST..)